

# **Constraints on the Geometry of the Seismic Rupture Plane in Subduction Zones a priori - a Probabilistic Approach**

---

**Gavin P. Hayes & David J. Wald**  
**U.S. Geological Survey National Earthquake  
Information Center**

# Talk Outline

- Background to problem - why we need to constrain subduction interface geometry.
- Procedure for constraining interface geometry -
  - data sets used, uncertainty assessment, data filtering and data set merging.
  - using data at a new 'reference location' to assess geometry
- Interface constraint examples -
  - Sumatra trench in the source area of the 03/28/2005 Mw8.6 Nias Island Earthquake.
  - Northern Chile trench in the source area of the 11/14/2007 Mw7.8 Antofagasta Earthquake.
  - Kamchatka trench in the source area of the great 11/02/1953 Mw9.0 earthquake.
- Implications for source inversions of earthquake slip distribution.
- Main observations & conclusions.

# Motivation

Many earthquake source inversions require information related to the geometry of the ruptured fault plane. Knowledge of that surface is uncertain.

Assumed geometries (e.g. from CMT inversions) often disagree with other data sets - e.g. historic EQ hypocenters and surface fault break locations.

Fault geometry mislocation can map into significant error in the final spatial and temporal slip patterns of source inversions.

Significant amounts of a priori data related to fault geometry are available to us - principally earthquake locations from several catalogs, earthquake focal mechanisms (CMTs), and surface fault break locations.

We can use these data to more accurately constrain the location of the seismic rupture plane of subducting slabs, combining them in a probabilistic sense to invert for the 'most likely' interface geometry.

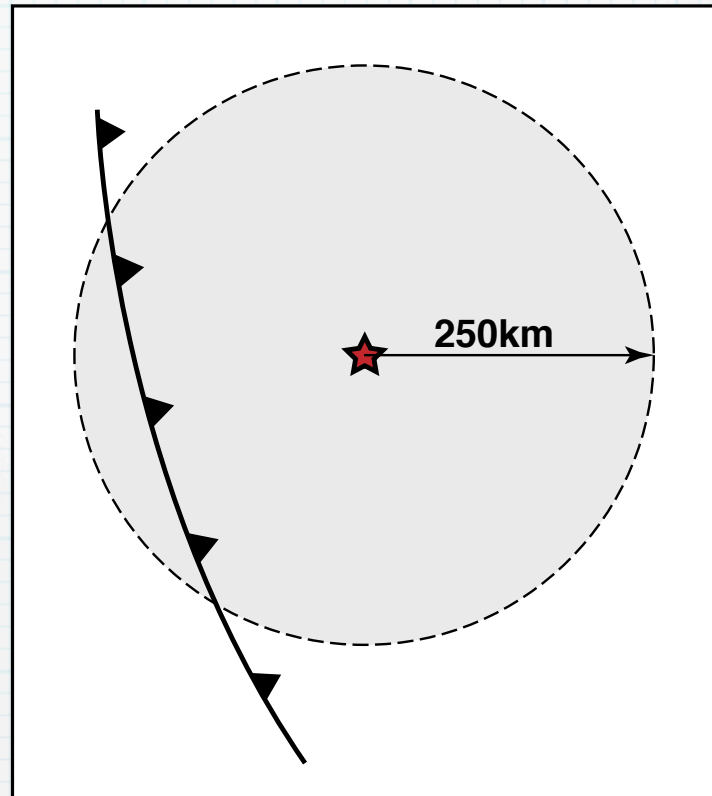
# Procedure to Constrain Slab Interface

- This approach calculates the most likely orientation (strike & dip) of a planar approximation to the shallow, seismogenic portion of the subduction interface.
- We incorporate events from 3 major historic catalogs: gCMT, NEIC PDE, and the EHB catalog of Engdahl, et al. (1998).
- Any single event is only considered once, using a hierarchy of catalogs based on epicentral location uncertainty: (i) EHB, (ii) NEIC, (iii) gCMT.
- Each interface is pinned at the trench, whose location and depth are considered known (plate boundary files of Tarr et al. (2008), bathymetry from the Marine Geoscience Data System, <http://www.marine-geo.org>).
- The 'reference location', about which the trench is constrained, can be a point of the users choice, or that of a 'new' earthquake (NEIC & PDE locations).
- In the latter case, the inversion predicts the 'most likely depth' of the event assuming it ruptured the plate interface.



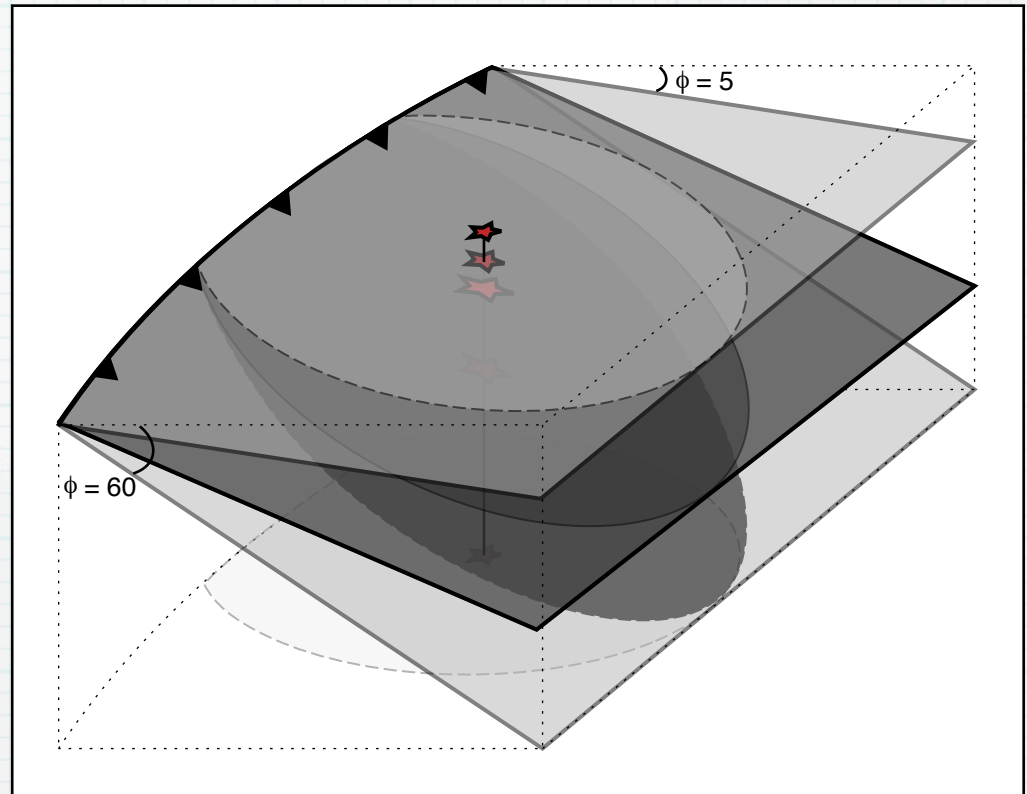
# Event Selection and Filtering, Step 1

- All well-constrained events from the gCMT catalog (using the criteria of Frohlich & Davis, 1990), and within 250 km of the reference location are selected.



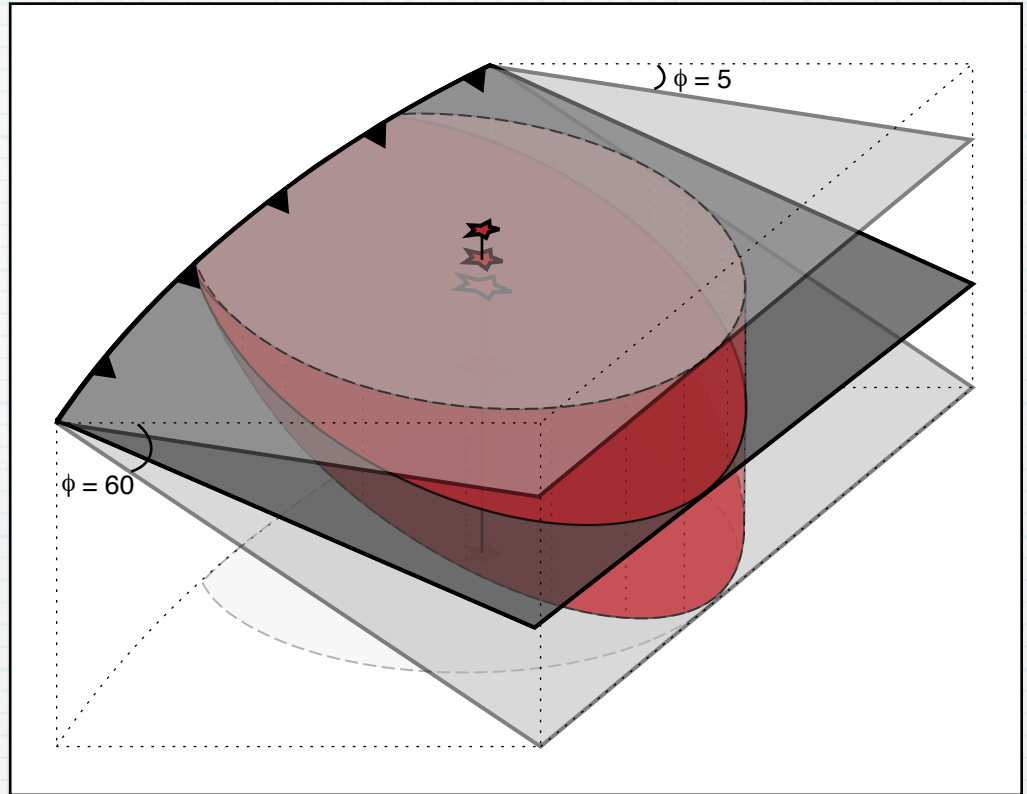
## Event Selection and Filtering, Step 2a

- All events shallower than the equivalent depth of a plane dipping  $5^\circ$ , and deeper than the equivalent depth of a plane dipping  $60^\circ$ , at the same distance from the trench are removed from the catalog.



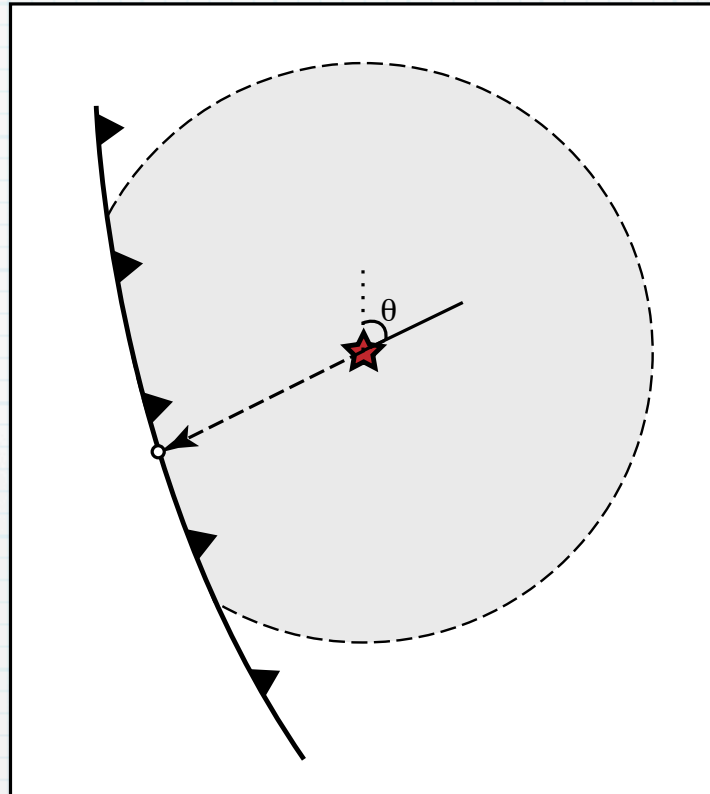
## Event Selection and Filtering, Step 2b

- This filter reduces the effects of upper-plate and deep earthquakes from the inversion.
- The red shaded region represents the remaining cylinder of events.



## Event Selection and Filtering, Step 3

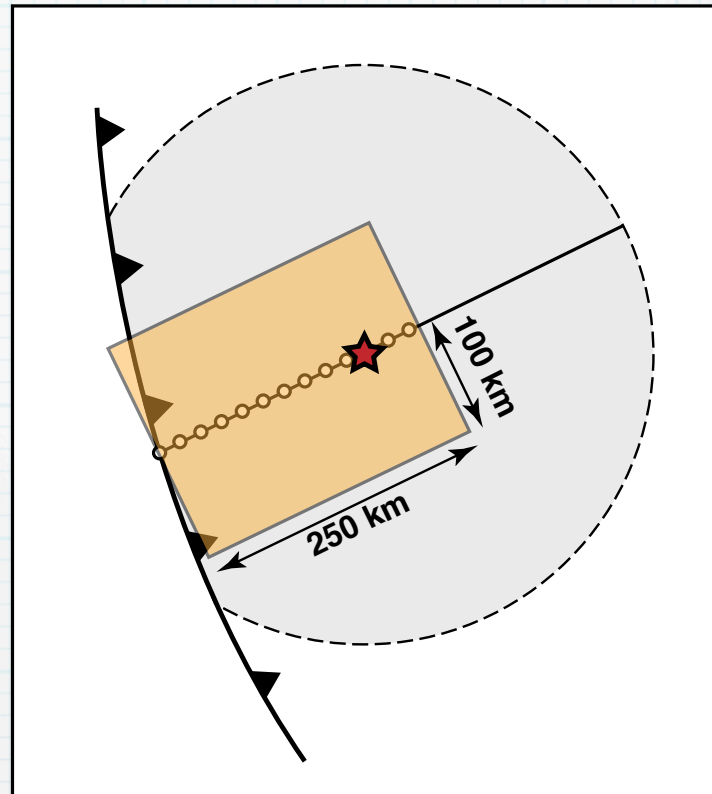
- Using the remaining mechanisms, the average CMT strike is calculated. This angle is assumed to represent the approximate direction of subduction.
- From the reference location, we project back to the nearest point on the trench with this angle to establish the start point of our reference profile.





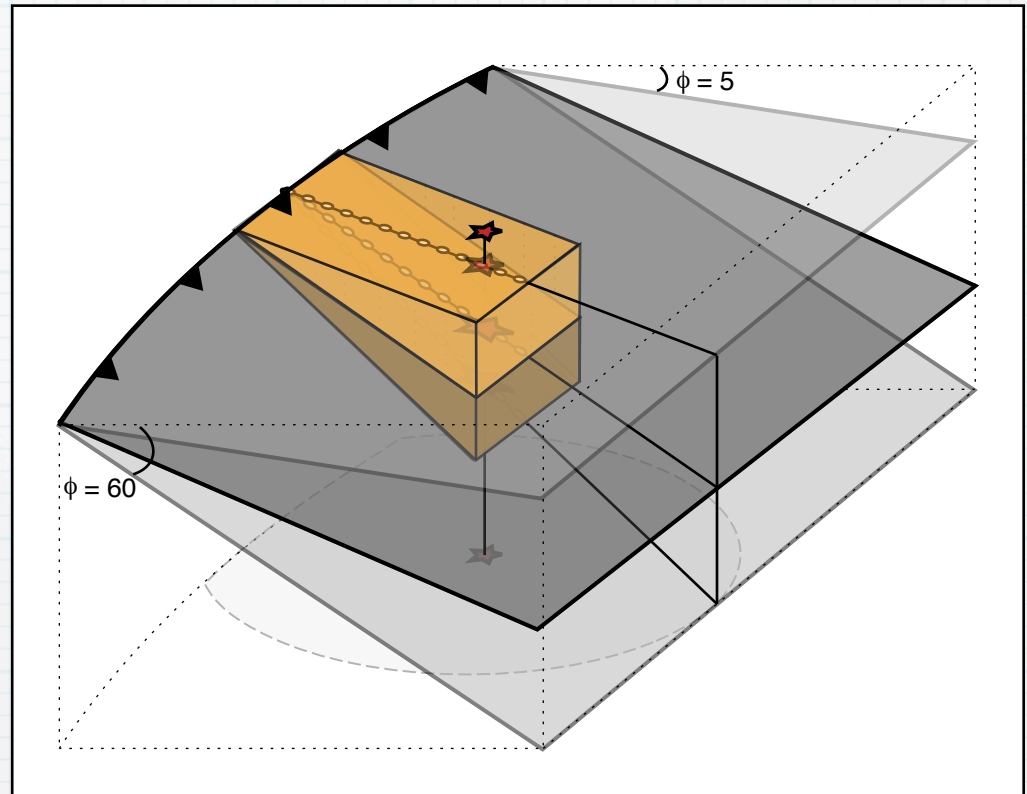
## Event Selection and Filtering, Step 4

- Using the trench location and angle from step 3, we construct the reference profile. All events greater than 100 km distance from this profile, in a direction perpendicular to that profile, are removed.



## Event Selection and Filtering, Step 5

- The remaining region of events is shaded here in orange, encompassing a rectangular region about the reference profile, between planes dipping at angles of  $5^\circ$  and  $60^\circ$ .

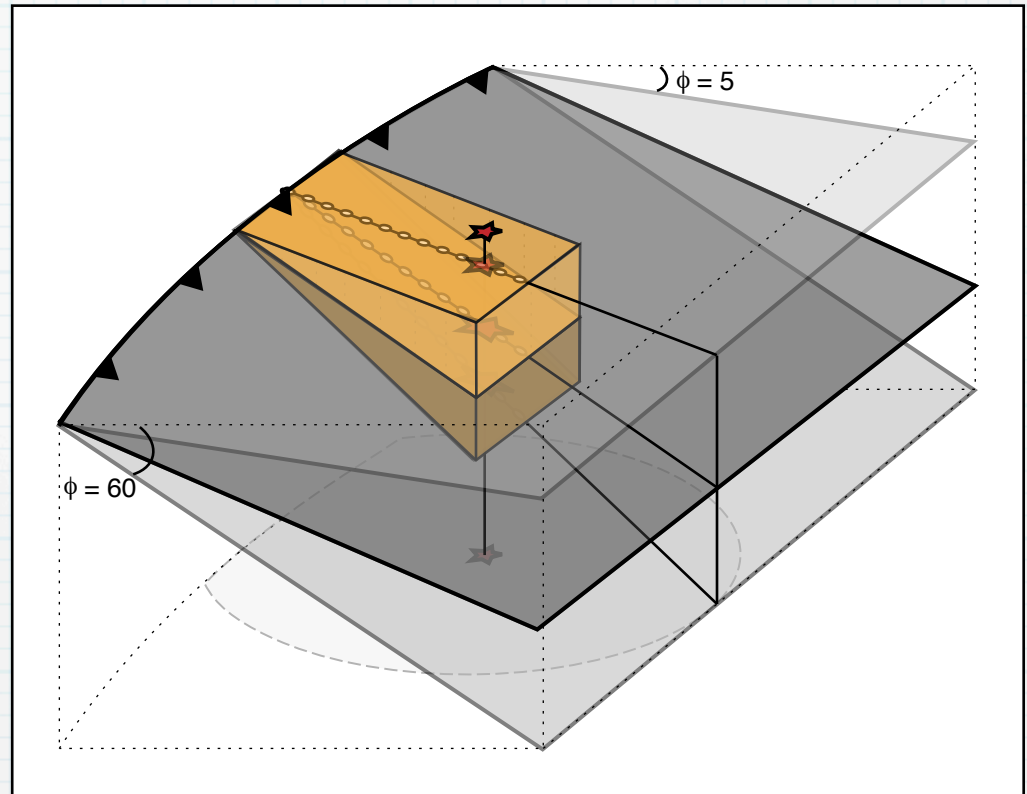


# Event Selection and Filtering, Step 5

- For those events selected, we construct Normal Distribution Probability Density Functions about their reported depth, whose variance is based on reported depth error (EHB), or depth uncertainty w.r.t. the EHB catalog (NEIC & gCMT).

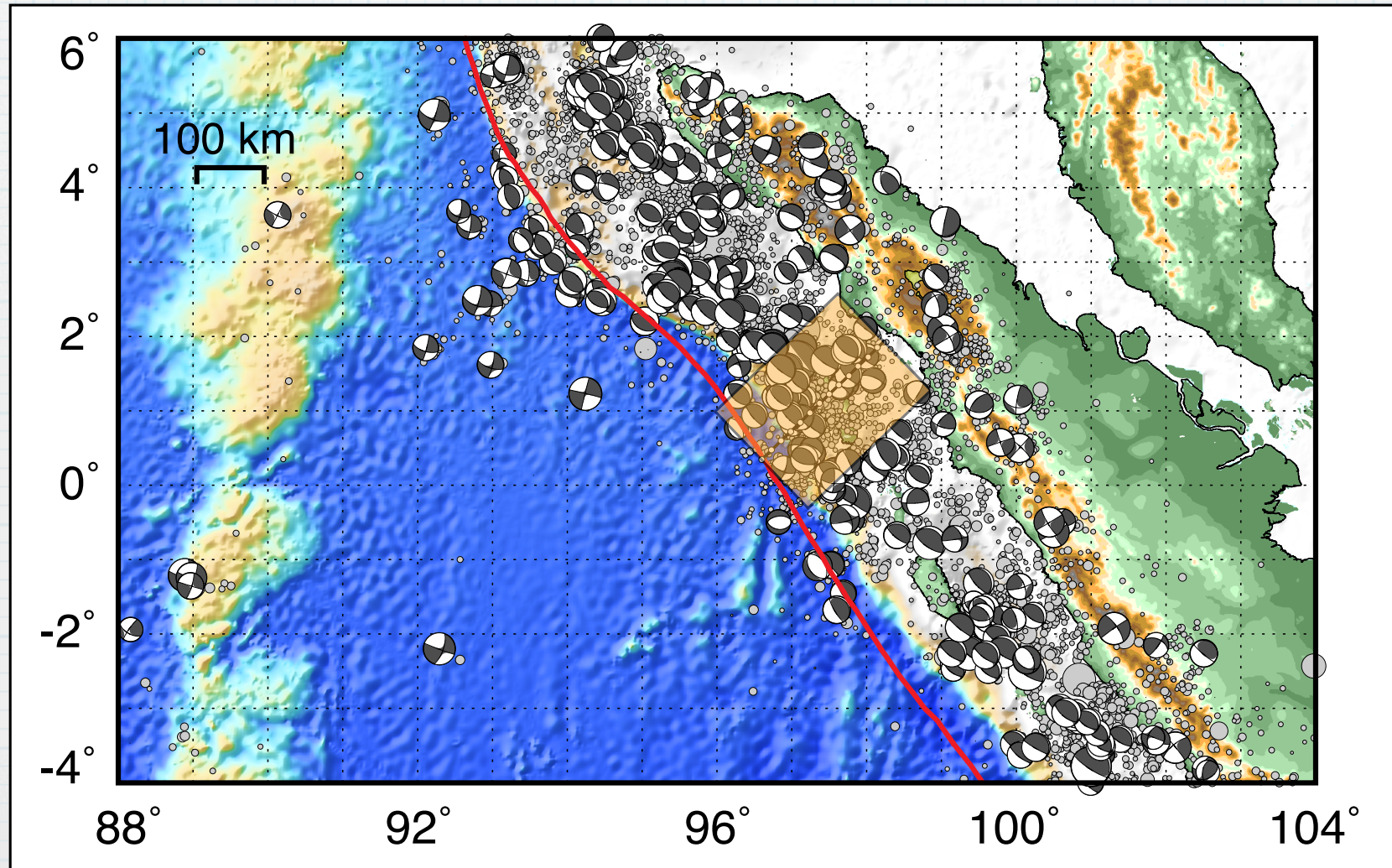
- All events are also weighted by magnitude, with larger events receiving higher weighting.

- The dip of the subduction zone is computed in a direction perpendicular to the average strike of selected events by fitting an inclined plane through these PDFs. We calculate the probability of the plane dipping at angles ranging from  $5^{\circ}$ - $60^{\circ}$ .



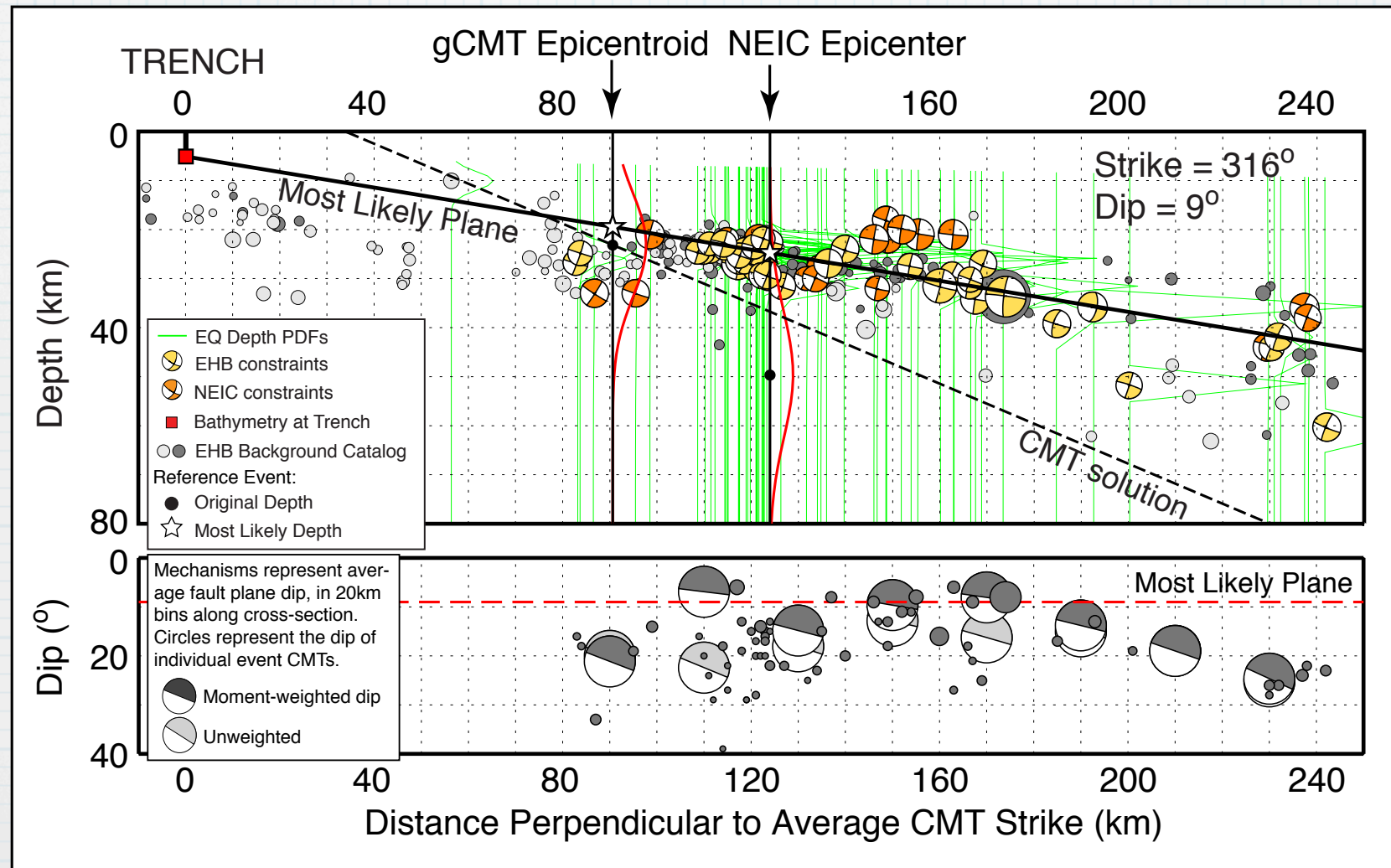


# Subduction Zone Constraint, Sumatra (01/22/2008, Mw 6.2 Nias Island Earthquake)

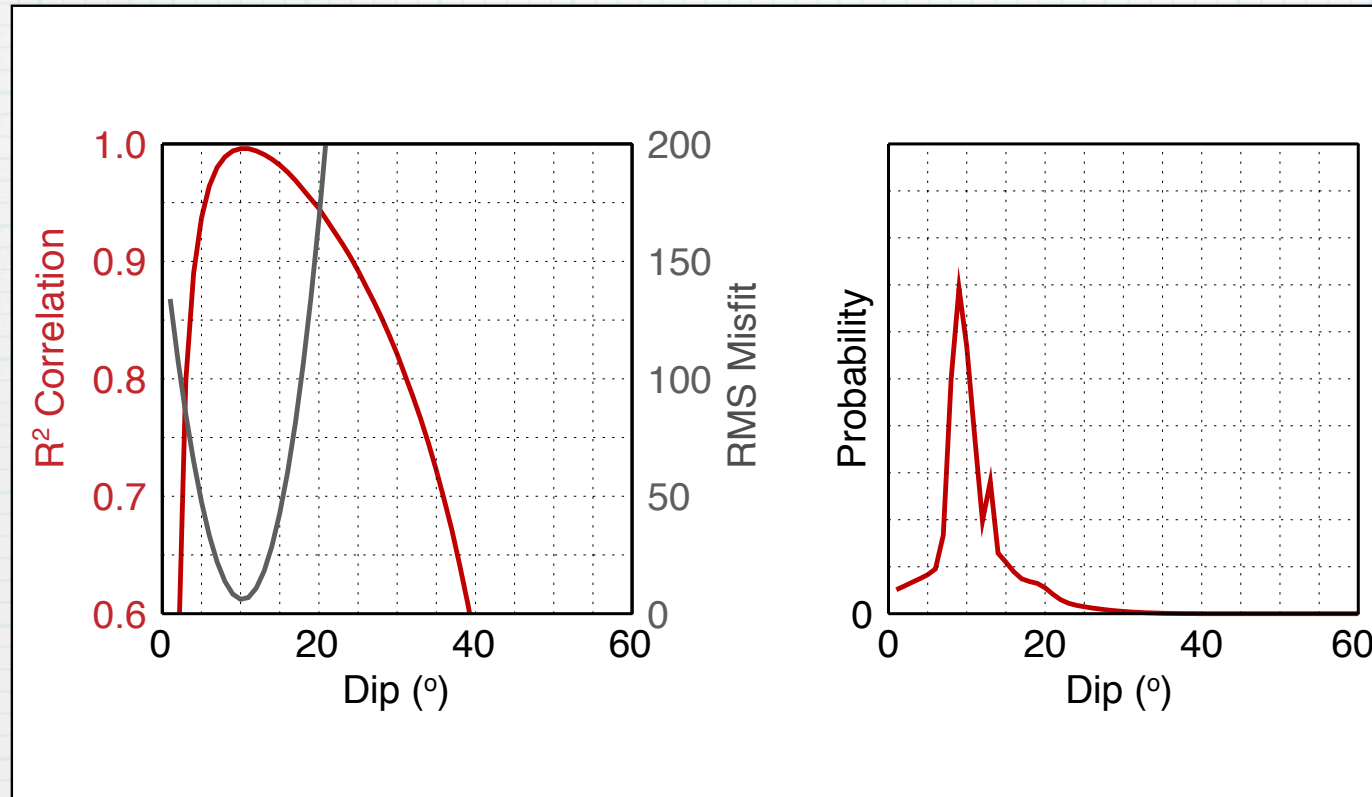




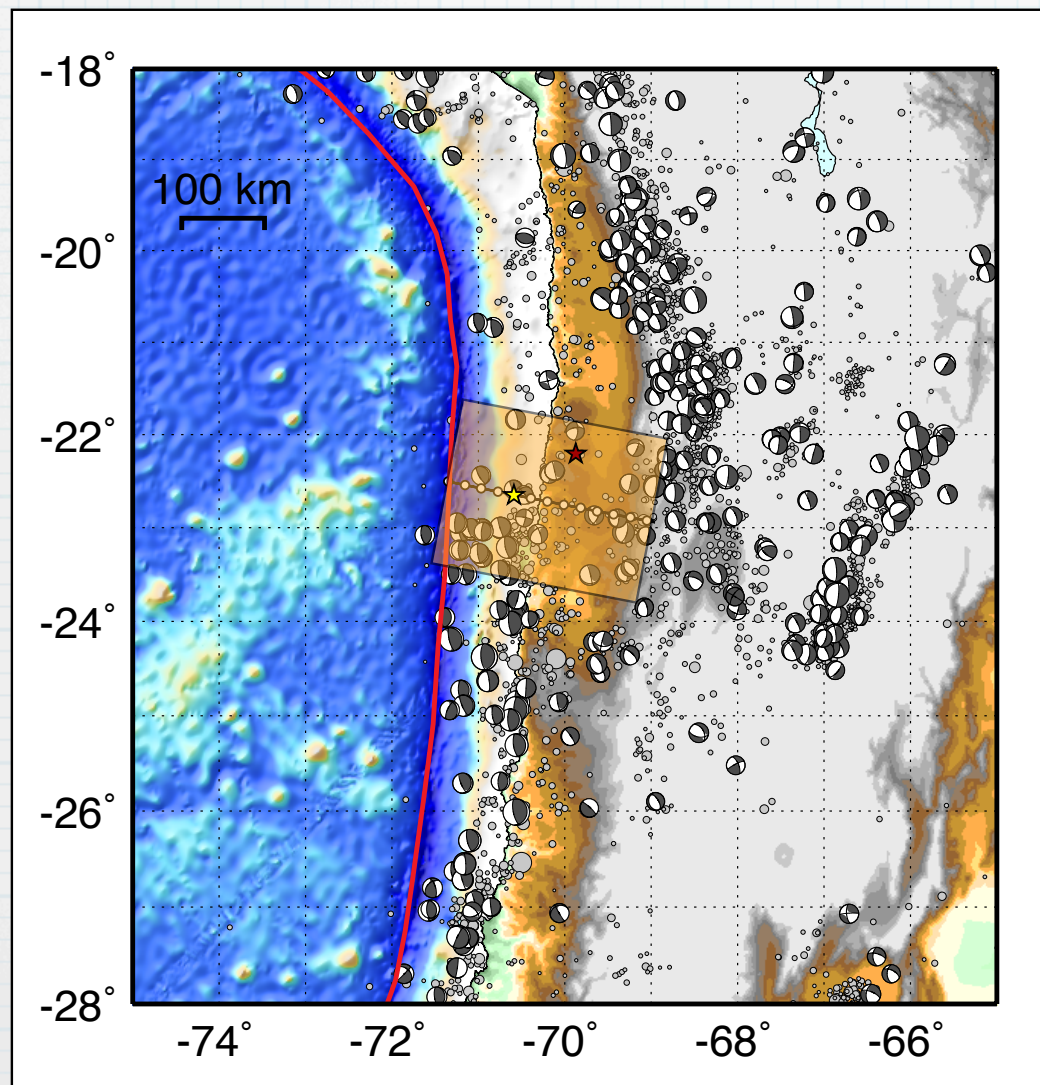
# Subduction Zone Constraint, Sumatra (01/22/2008, Mw 6.2 Nias Island Earthquake)



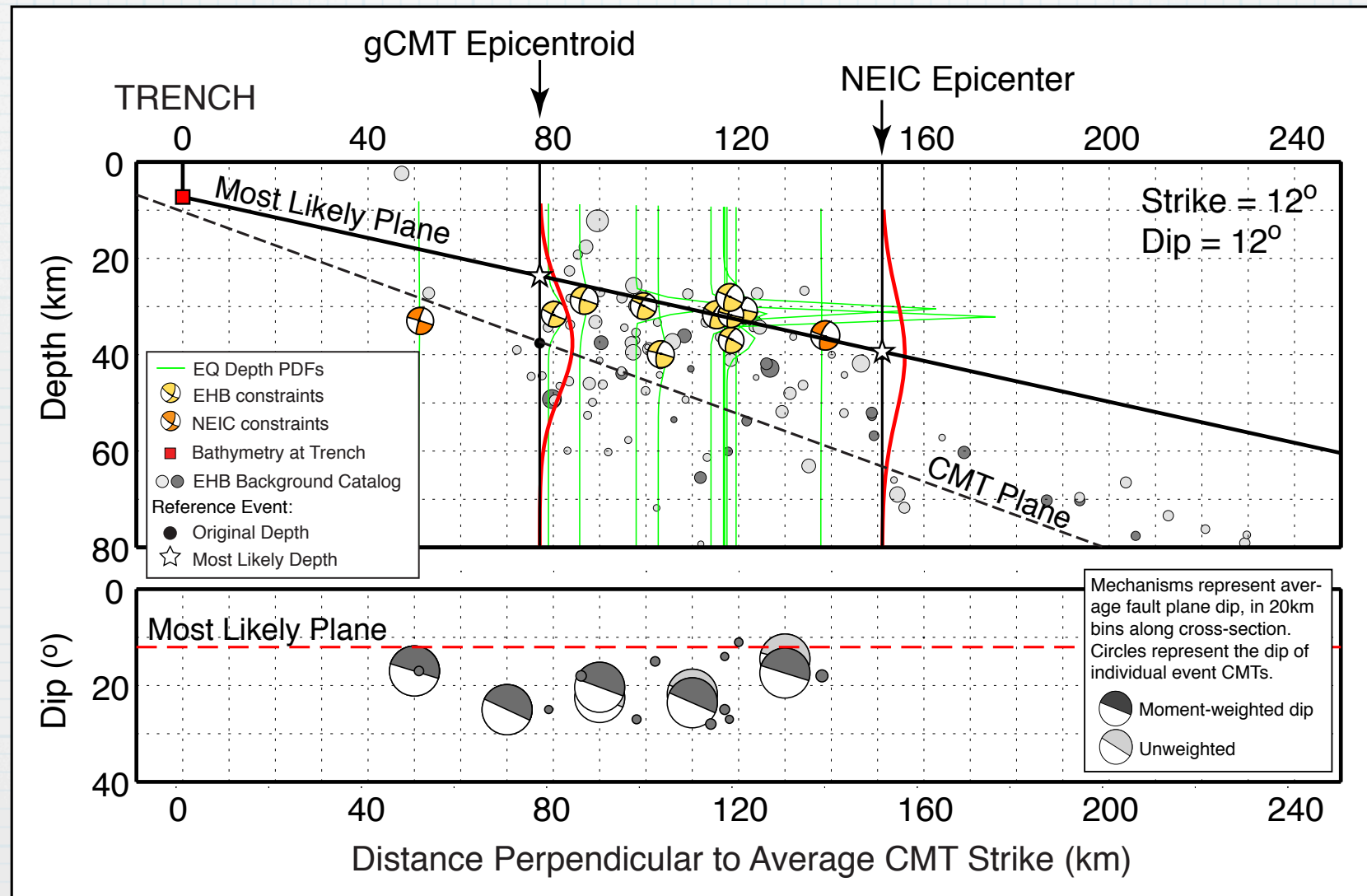
# Subduction Zone Constraint, Sumatra (01/22/2008, Mw 6.2 Nias Island Earthquake)



# Subduction Zone Constraint, Northern Chile (1 1/4/2007, Mw 7.8 Antofagasta Earthquake)

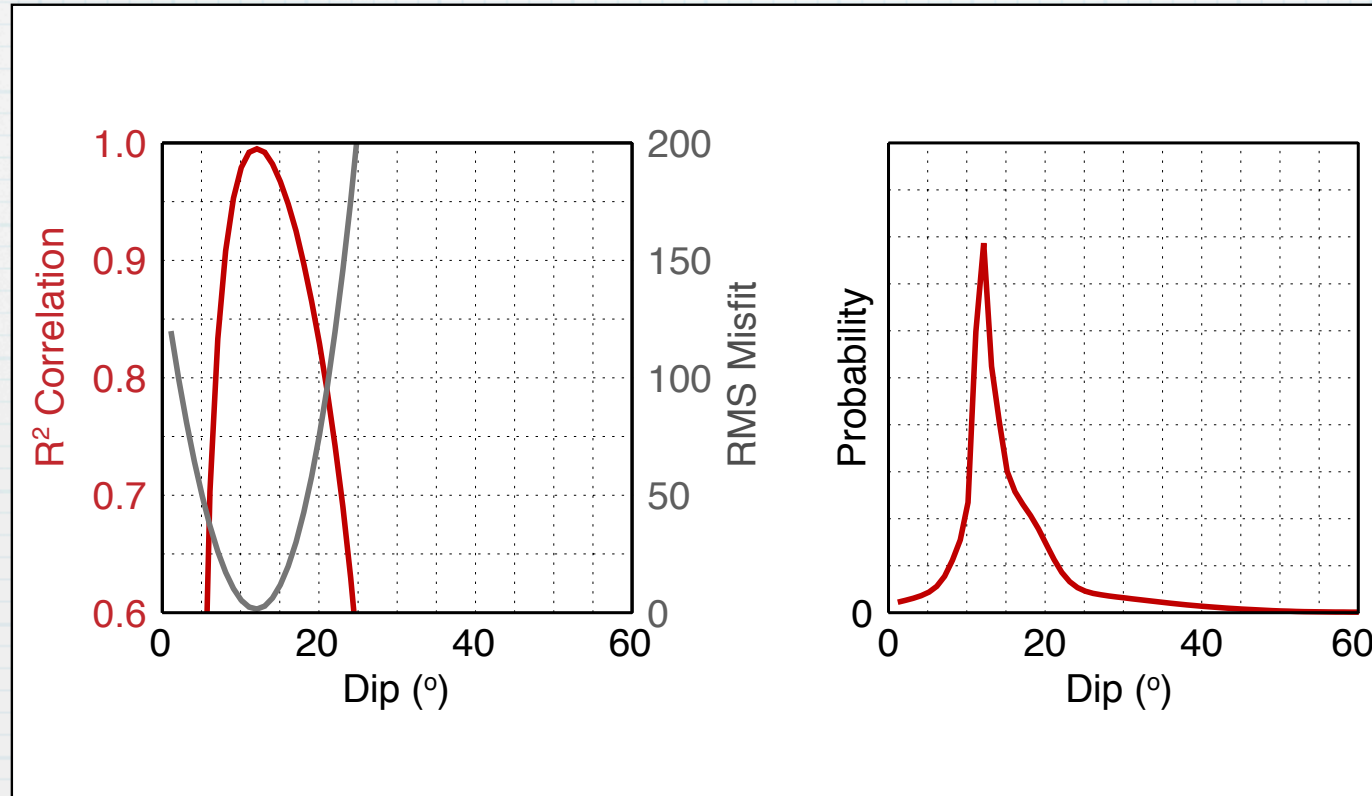


# Subduction Zone Constraint, Northern Chile (1 1/4/2007, Mw 7.8 Antofagasta Earthquake)



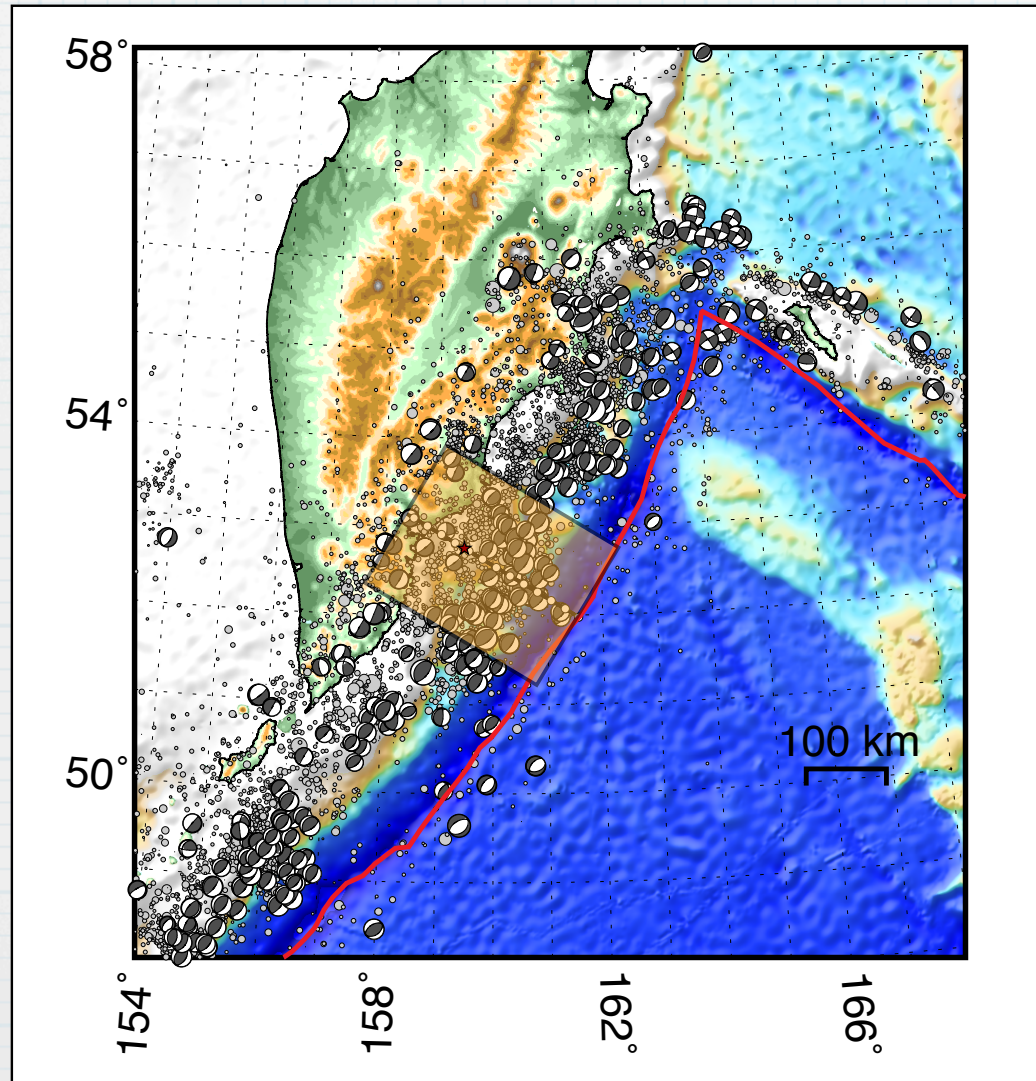


# Subduction Zone Constraint, Northern Chile (1 1/4/2007, Mw 7.8 Antofagasta Earthquake)



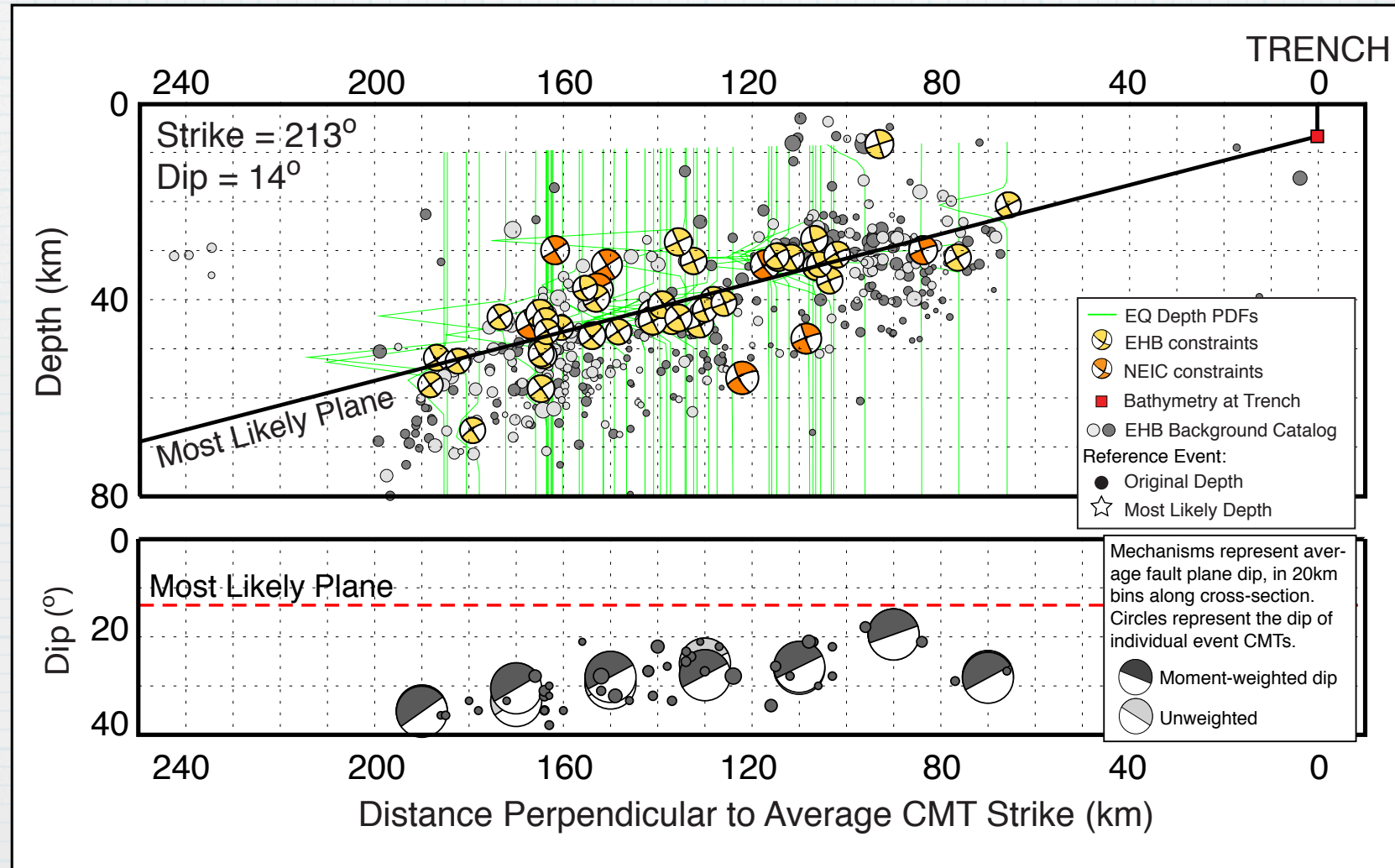
# Subduction Zone Constraint, Kamchatka

(Source area of Great 11/04/1952 Mw9.0 Earthquake)



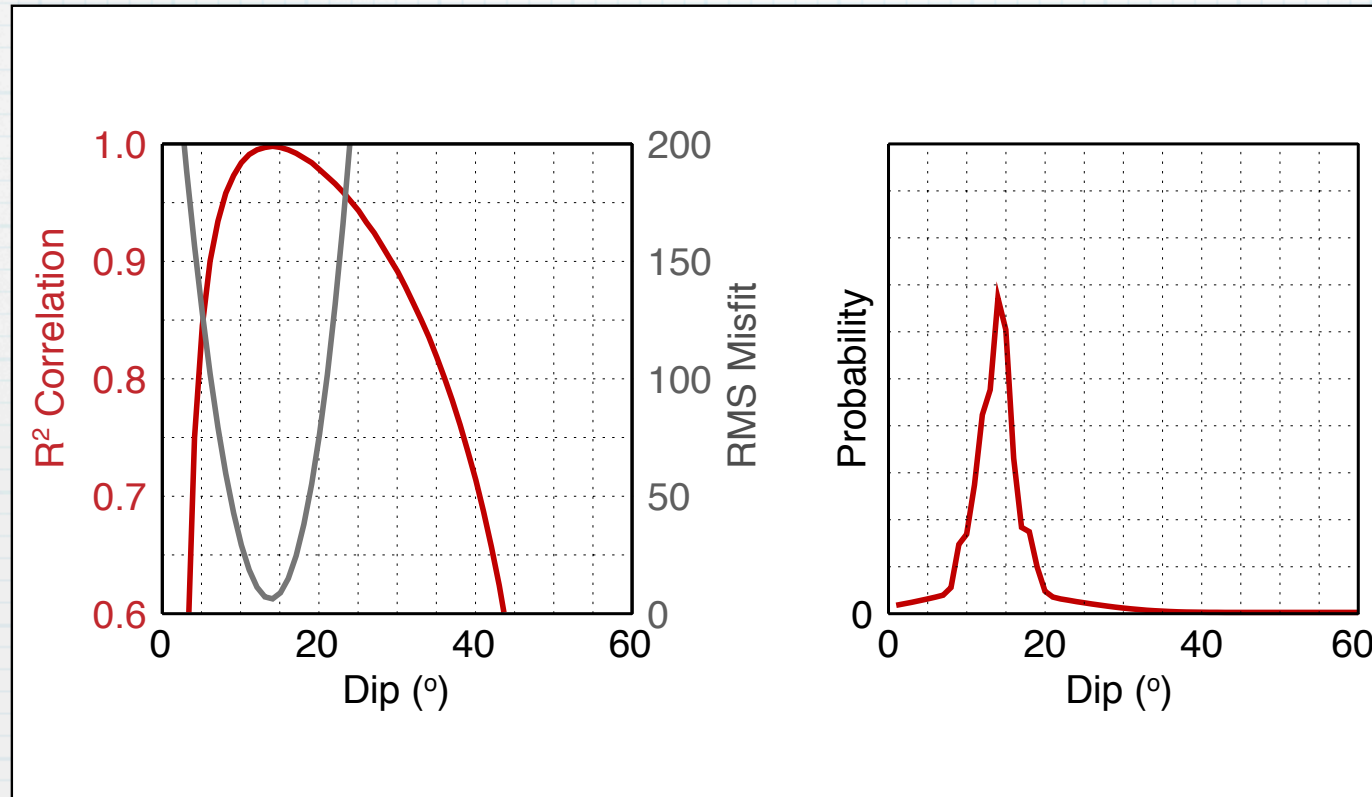
# Subduction Zone Constraint, Kamchatka

## (Source area of Great 1 1/4/1952 Mw9.0 Earthquake)



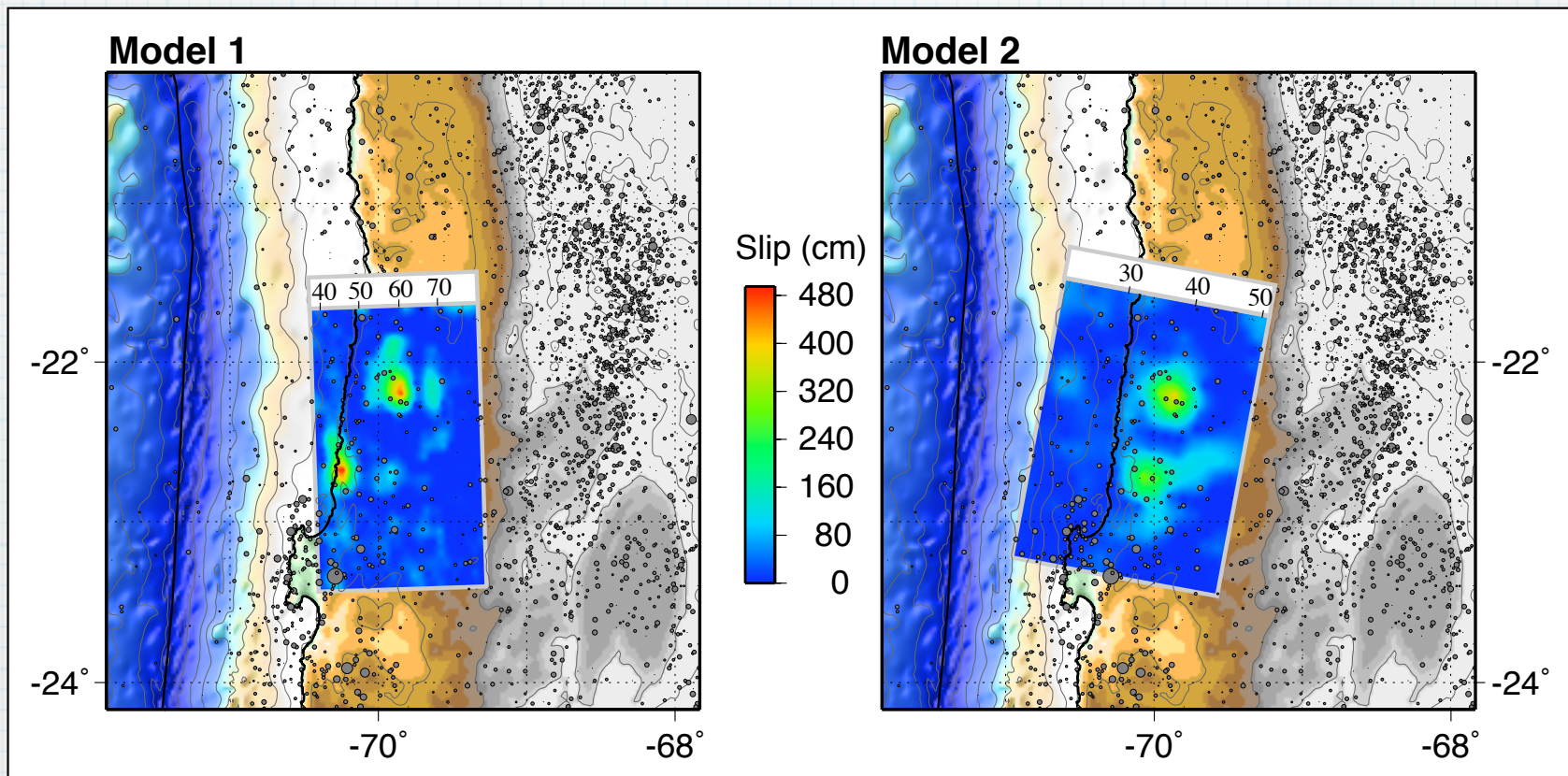
# Subduction Zone Constraint, Kamchatka

## (Source area of Great 11/04/1952 Mw9.0 Earthquake)



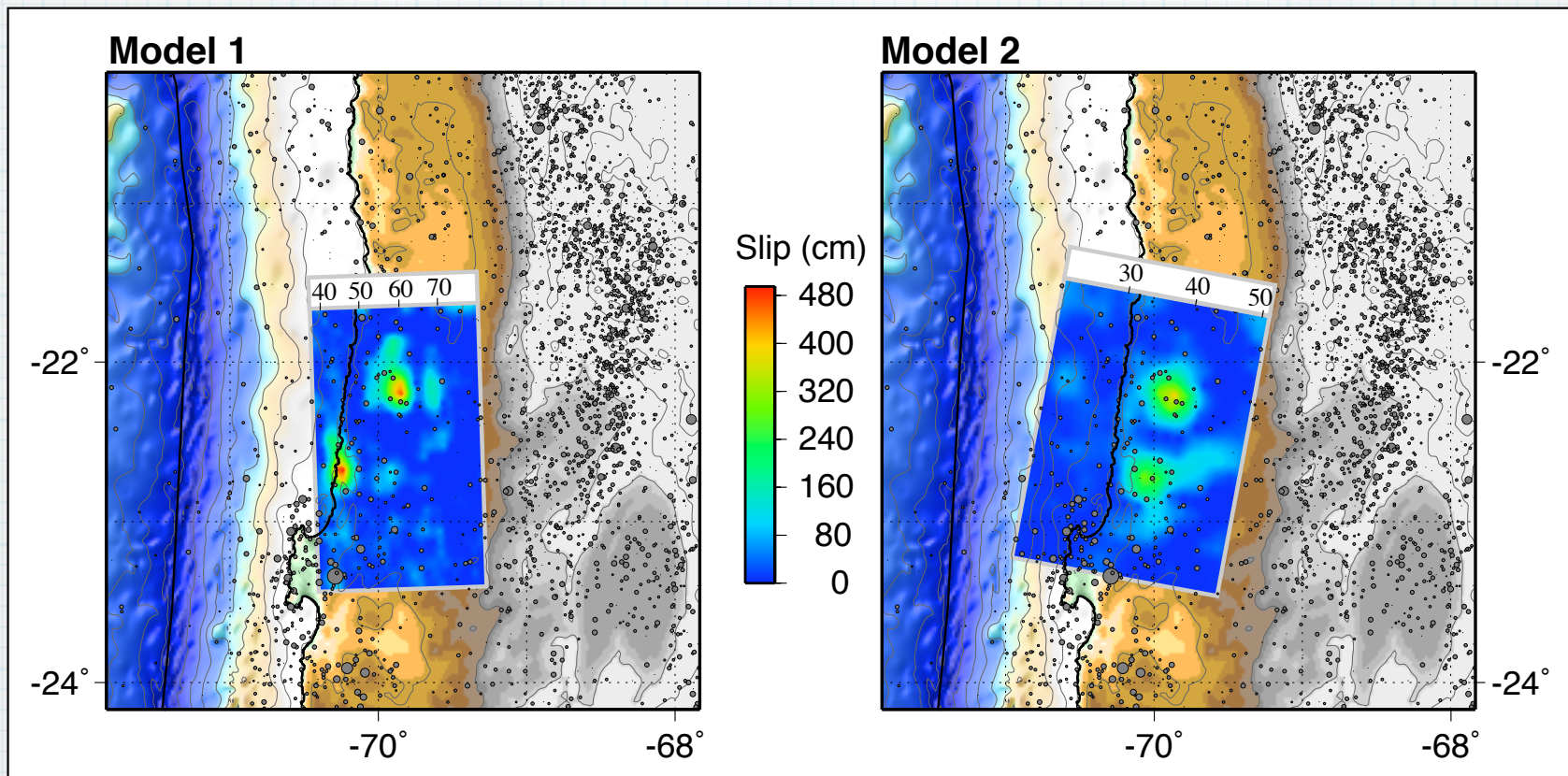


# Finite Fault Model Slip Distributions - Antofagasta



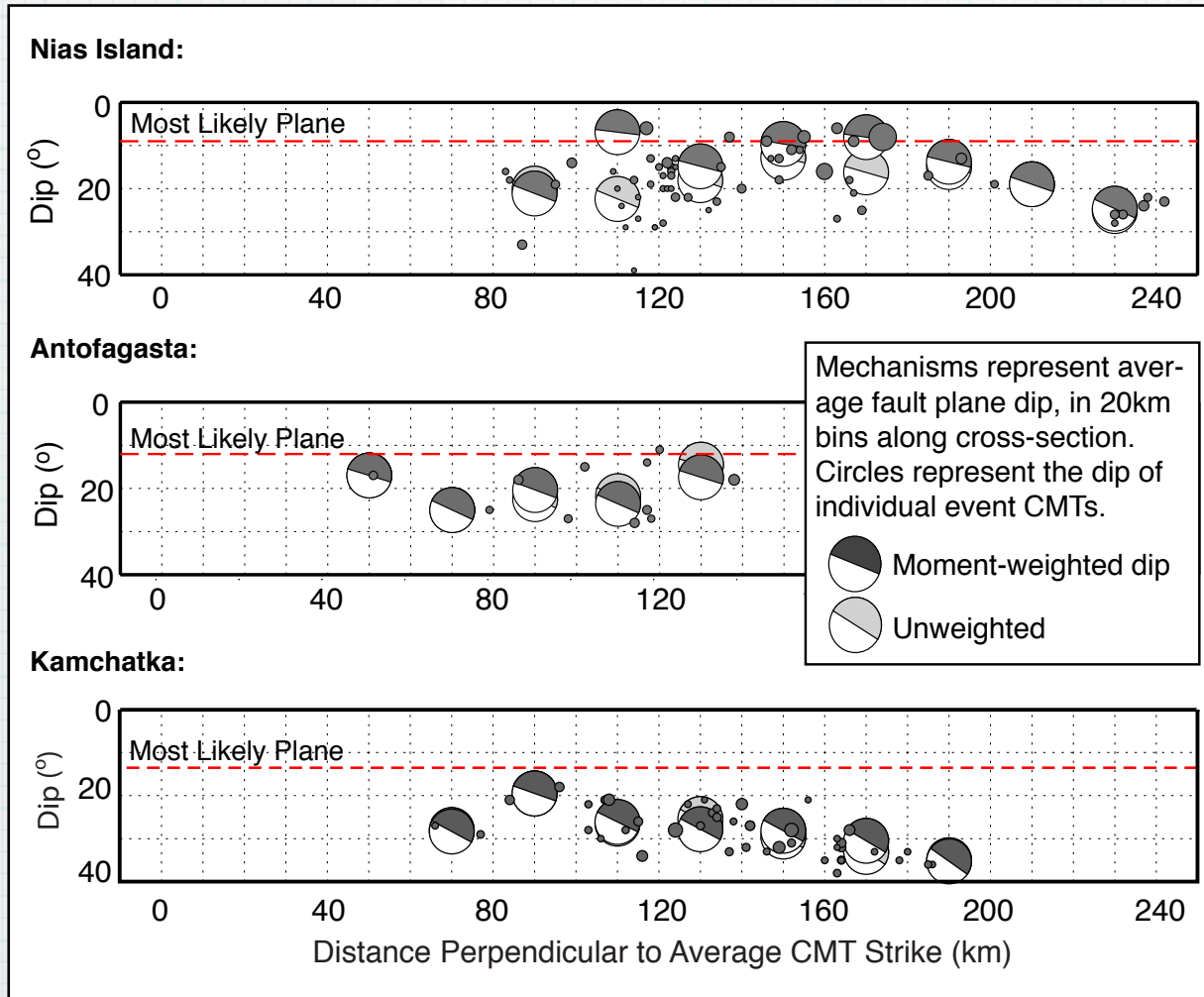
- Model 1 = Quick FFM from NEIC, using fault geometry of the gCMT solution, produced within hours of the event.
- Model 2 = FFM using revised faulting geometry from our inversion.
- Slip patch located near the hypocenter moves 20 km shallower in revised model.

# Finite Fault Model Slip Distributions - Antofagasta



- Such results become significant for any subsequent models that rely on the depth and distribution of slip:
  - Ground shaking estimates (leading to rapid response decisions)
  - Tsunami modeling & predictions

# Dip Discrepancies - Interface Dip vs CMT Dip



- Uncertainties/errors in CMT inversions (e.g. moment/dip trade-off)?

- CMT bias caused by 1D velocity models?

- Roll-over of slabs; i.e. non-planar geometries?

- **REAL SIGNAL?** i.e. evidence for (smaller) ruptures on structures close to and at (generally) higher angles than the main thrust interface.



# Conclusions (1)

This work presents a new approach for constraining the interface geometry in the shallow, seismogenic portion of subducting slabs using information from historic earthquake catalogs, sea floor trench locations, and probabilistic assessments of location uncertainties.

Planar geometries match data well for the shallow slab (to depths of ~60km).

Complications arise when seismicity is diffuse (e.g. Cascadia), slabs roll-over very quickly (e.g. Solomons) or there exist high levels of upper-plate seismicity (e.g. Kuriles).

New geometries become inputs to subsequent finite-fault models. These inversions show significant differences in the temporal and spatial patterns of slip when compared to models produced using a best fitting CMT plane.



## Conclusions (2)

Systematic differences exist between the dip of our most-likely slab interface and the dips of best-fitting fault planes from individual CMT solutions on or near the subduction thrust in all subduction zones analyzed.

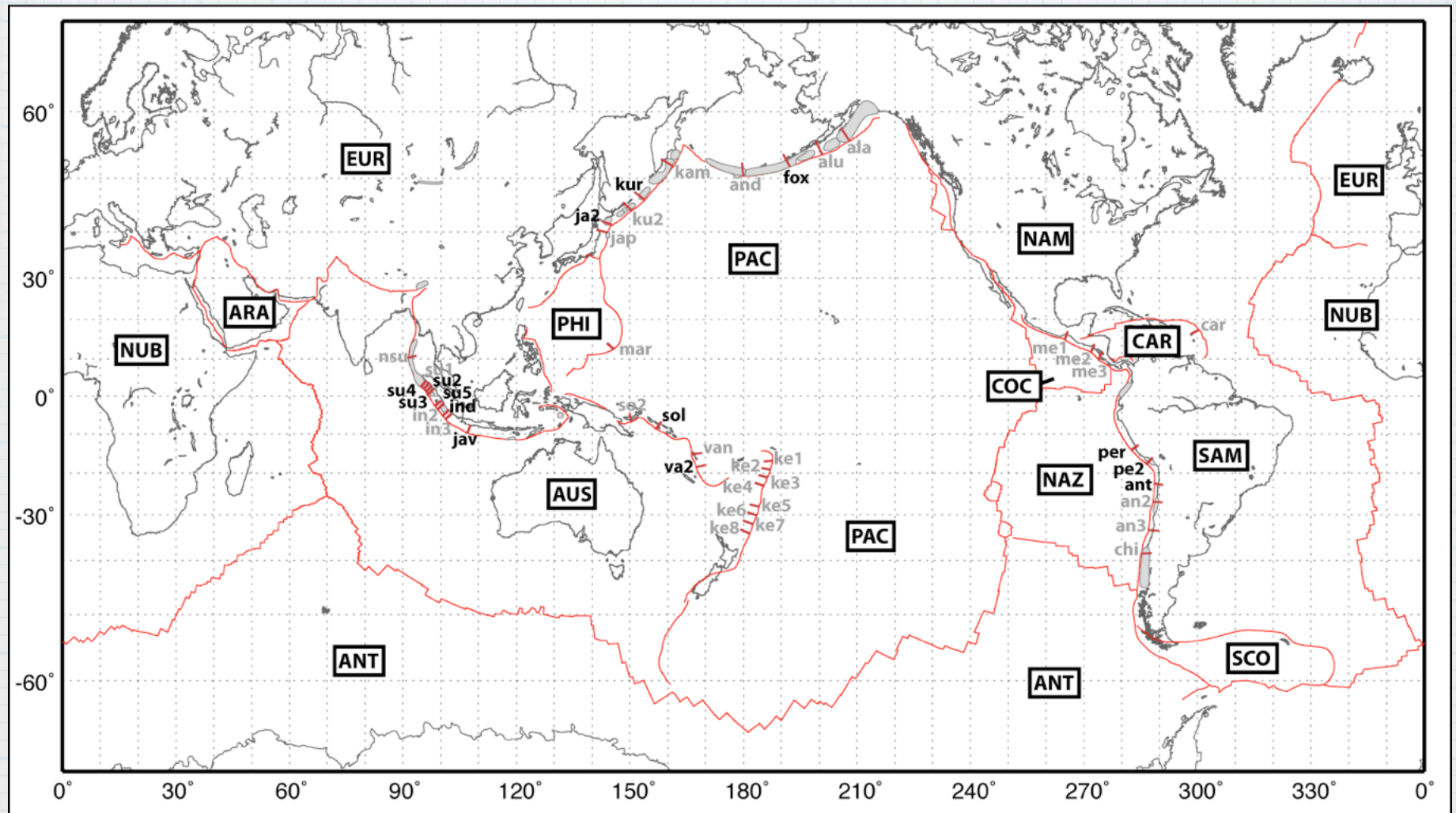
In general, CMT dips are steeper than is the subduction thrust. This discrepancy may be magnitude-dependent, with bigger events aligning more closely with the main interface.

Evidence for sub-parallel faulting about the main subduction thrust interface??

-----

Fault geometry constraint is fundamental to the accuracy of earthquake source inversions. These methods will be incorporated into the NEIC's Fast Finite Fault (FFF) project for the rapid determination of slip distributions of future large earthquakes.

# Global Subduction Zone Constraint



All Locations analyzed globally. Black = New earthquake reference: Grey = User-specified location (often historic great ruptures).

**-END-**

# Finite Fault Model Slip Distributions

